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Assessment of Ventricular Septal Defect Closure by Intraoperative Epicardial Ultrasound

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Intraoperative epicardial two-dimensional echocardiographic imaging, color flow mapping and contrast echocardiography were used in 31 patients after patch closure of a ventricular septal defect to determine their respective values in the assessment of residual shunting after cardiopulmonary bypass and for the prediction of long-term results.

Epicardial imaging showed no incidence of patch dehiscence. Residual shunting detected by color flow mapping or contrast echocardiography was graded into one of four categories (0 to III). Real time analysis of color flow mapping studies suggested no shunting (grade 0) in 2 patients, grade I shunting in 20, grade II in 8 and grade III in 1; contrast studies suggested grade 0 in 15, grade I in 6, grade II in 8 and grade III in 2. Interobserver variation in real time encoding of grade I or II shunting was 25% by color flow mapping and 6% by contrast echocardiography. Subsequent frame by frame analysis revealed that both diastolic and early systolic right ventricular turbulence gave rise to false positive results during real time analysis of color flow mapping studies. Color flow mapping allowed exact localization of residual shunting, whereas contrast echocardiography allowed better semiquantification.

Postbypass results were correlated in 30 patients with late postoperative precordial studies (mean interval 7.5 months). Persistent shunts were found in 6 (20%) of 30 patients. No patient required reoperation for residual shunting. The predictive value of immediate grade I or II shunting as a marker for persistent long-term shunting was poor, whereas both patients with immediate grade III shunting had shunt persistence, indicating that immediate revision should be considered in such patients.

Intraoperative epicardial ultrasound is valuable for the immediate exclusion of important residual shunting after ventricular septal defect closure. Maximal information is obtained when color flow mapping and contrast echocardiography are used in combination.

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Residual interventricular shunting is a frequent finding after surgical patch closure of ventricular septal defects. Follow-up cardiac catheterization data (1–3) from large series of patients who underwent ventricular septal defect closure indicate that a hemodynamically significant residual defect occurs in up to 10% of patients and an insignificant residual shunt in a further 10% to 18%. Using pulsed wave Doppler ultrasound in the immediate postoperative period, Stevenson et al. (4) reported residual interventricular shunting in 93% of patients, with a high incidence of spontaneous closure taking place during the first few days after operation.

An intraoperative monitoring technique that would allow the definite exclusion of significant residual shunting or that would distinguish between those small defects that will close spontaneously and those that will persist would be highly desirable because the persistence of interventricular shunting has a direct bearing on both postoperative morbidity and the requirement for early or late reoperation. In addition, multiple ventricular septal defects remain a problem in preoperative diagnosis; in the presence of nonrestrictive hemodynamics, multiple defects may be missed by both Doppler ultrasound and angiography (5–7). After closure of any nonrestrictive defect, the existence of additional overlooked defects has to be ruled out in every case to optimize surgical results (8).

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The use of epicardial contrast echocardiography has previously been reported (9–11) to be of value in the exclusion of residual shunting immediately after repair, whereas the use of epicardial two-dimensional echocardiography imaging alone was found to have inherent problems (12,13). Color flow mapping could expand the potential value of intraoperative ultrasound because this technique potentially allows compensation for some of the limitations encountered when using epicardial two-dimensional and contrast echocardiography, but its use in patients with a ventricular septal defect has so far been limited (14).

We therefore used intraoperative epicardial two-dimensional echocardiographic imaging, contrast echocardiography and color flow mapping after the surgical closure of ventricular septal defects to judge the relative values of these techniques for the immediate exclusion of a significant residual defect and for the prediction of risk of long-term residual shunting.

Methods

Study patients. Thirty-one patients undergoing surgical closure of a congenital ventricular septal defect were studied. Hospital ethical approval (Academisch Ziekenhuis Rotterdam) was granted before commencement of the study protocol. The age at operation ranged from 2 weeks to 43 years (mean 2 years 9 months, median 15 months). The ventricular septal defect was either an isolated defect or part of a more complex malformation. No patient in this study was diagnosed preoperatively to have multiple ventricular septal defects by either Doppler ultrasound investigations or cardiac catheterization. The preoperative diagnosis was isolated ventricular septal defect (n = 17); tetralogy of Fallot (n = 7); atrioventricular septal defect (n = 5) and double outlet right ventricle (n = 2). The defect was closed in every patient by a prosthetic patch that was sutured into place by a continuous running monofilament suture along its entire circumference.

Intraoperative studies. Intraoperative epicardial echocardiographic studies were performed both before and after cardiopulmonary bypass with use of a Toshiba SSH 65 or SSH 160A ultrasound machine and standard precordial transducers. Direct epicardial cross-sectional imaging was undertaken with a 5 MHz probe, and color flow mapping with a 3.75 MHz probe. The probes and the connecting cables were packed in long tube-shaped sterile plastic bags that contained about 5 ml of ultrasound gel at their tip, and were then passed into the surgical field where they remained during the operation. Warm saline solution was poured into the pericardial cradle to enlarge the contact area between the transducer and the epicardium and reduce mechanical irritation of the heart, which may cause arrhythmias. Studies were recorded continuously on videotape.

Two-dimensional echocardiographic images of modified long-axis, short-axis and four chamber planes were obtained by placing the transducer directly onto the right ventricular epicardium and by angulating and rotating the probe. The four chamber view was obtained from a scan position on the mid portion of the anterior right ventricular surface toward the acute margin. Short- and long-axis views were obtained by using imaging planes comparable to those of precordial examinations. Second, color flow mapping studies were performed, during the postbypass flow mapping studies, emphasis was placed on the assessment of any flow abnormalities along the interventricular septum or adjacent to the suture line of the patch.

Epicardial contrast echocardiography for the detection of residual shunting was performed only during the postbypass study. The contrast medium (hand-agitated patients' blood and saline solution) was injected through a left atrial line. The amount of injectate varied according to the size of the patient, but care was taken to achieve a uniform and dense contrast effect in the left ventricle. Central venous infusions were discontinued during the study whenever feasible and no concurrent venous injections of drugs were administered because these could have given rise to "false positive" contrast effects. Not more than three contrast injections were used in any patient. Scan positions were chosen individually in an attempt to detect the existence and to localize the site of any potential residual shunting at the same time. After closure of perimembranous inlet defects, four chamber views were used, whereas long- and short-axis views were used after closure of (perimembranous) outlet defects.

Intraoperative evaluation. Postbypass epicardial studies were first interpreted on-line and in real time, and results were discussed with the cardiac surgeon before closure of the chest. The intraoperative studies of all 31 patients were later reviewed and analyzed by two independent observers on two occasions 3 months apart. These observers were not involved in the follow-up studies. On the first occasion, the intraoperative studies were reviewed at normal speed, and on the second occasion 3 months later, also both at slow speed and on a frame by frame basis.

The evaluation of the intraoperative studies followed a predetermined semiquantitative approach. Evidence of residual shunting, detected by either color flow mapping or contrast echocardiography, was graded into one of four categories: 0, I, II and III. For semiquantification of color flow evidence of residual shunting, the appearance and extent of any peripatch or paraseptal flow disturbance, depicted in the color flow maps as turbulence, was assessed. Semiquantification of residual shunting detected by contrast echocardiography was attempted by comparing the relative densities of contrast achieved in the ventricles (Table 1).

Significant residual shunts (grade III) were suspected in cases where color flow mapping showed a broad and expanding jet that reached far into the right ventricular cavity or

Table 1. Criteria for Intraoperative Semiquantification of Immediate Residual Shunting

Technique	Criterion	Semiquantitative Grading			
		Grade 0	Grade I	Grade II	Grade III
Color flow mapping	Peripatch or paraseptal turbulence	None	Flamelike, narrow	Broad, short	Broad, expanding
Contrast echocardiography	RV contrast effect relative to LV	None	<25%	<50%	<50%

LV = left ventricle; RV = right ventricle.

outflow tract, or when the contrast effect in the right heart chambers was judged to exceed 50% of the contrast density obtained in the left ventricle. A broad jet on color flow mapping and a right ventricular contrast density >25% of the left ventricular contrast density was designated a grade II residual shunt. A narrow flame-like jet on color flow mapping and <25% right ventricular contrast effect represented a grade I shunt. Grade 0 was used to code the absence of evidence of residual shunting in the immediate postbypass study.

The second step of the evaluation was the off-line, slow speed interpretation of the color flow mapping studies and reevaluation of the contrast studies at reduced speed. Frame by frame analysis of color flow mapping studies was used to determine the frame with the largest area of disturbed flow occurring either at the site of the patch or along the interventricular septum and to time the jet occurrence during the cardiac cycle. Timing was performed either by means of the continuously recorded electrocardiogram (ECG) or by observing intracardiac events such as mitral valve closure and opening. Early in the series, the connection with the central monitor for continuous ECG tracings frequently caused electric interference with the Doppler color flow mapping and thus it was switched off to allow optimal color information to be obtained. During frame by frame evaluation of the color flow maps, only holosystolic peripatch or paraseptal turbulence was judged to represent residual shunting; grading followed the same criteria as during real time analysis and was performed jointly by the two observers.

Follow-up. Thirty of the 31 patients were subsequently followed up at the Sophia Children's Hospital; one patient could not attend the follow-up study. The follow-up interval varied from 7 weeks to 15 months (mean 7.5 months). One patient was studied twice and a second patient three times during a follow-up period of 14 and 9 months, respectively. The ultrasound studies were performed by two investigators who were neither involved in nor aware of the results of the intraoperative studies. Both precordial color flow mapping and continuous wave Doppler studies were performed to exclude or detect any residual interventricular shunting. The hemodynamic significance of residual shunting was judged by combined clinical and Doppler ultrasound investigations, including Doppler-derived calculation of right ventricular pressure, assessment of pulmonary artery blood flow and right ventricular dimensions and the ECG findings. Before commencement of the study protocol it was agreed to perform cardiac catheterization and angiocardiography only on clinical grounds.

Risk of persistent shunting. The risk of having a persistent residual shunt was estimated independently and without knowledge of the follow-up results on the basis of results of the off-line analysis of the combined postbypass studies. A high risk of having a long-term residual shunt was assumed in those patients who showed a grade III residual shunt on either color flow mapping or contrast echocardiography. A moderate risk was assumed in those patients who were found by either technique to show grade II residual shunting immediately after bypass. Patients with grade I residual shunting were judged to be at low risk, and patients in whom neither technique demonstrated residual shunting after bypass were judged to be at no risk of long-term shunting.

Statistics. Where appropriate, data were compared with the chi-square test: significance was assigned to values of $p < 0.05$ for two-tailed tests.

Results

Real time analysis (Table 2). Immediate postbypass two-dimensional echocardiographic imaging showed no evidence of patch dehiscence in any patient studied (Fig. 1A). Epicardial color flow mapping suggested no residual shunting (grade 0) in 2 patients, a grade I shunt in 20 patients, a grade II shunt in 8 and a grade III shunt in 1. Interobserver variation for the real time coding of grade I or II residual shunting detected by color flow mapping was 25%. There was no disagreement between the independent observers in coding grade III and grade 0 shunts. Contrast echocardiographic studies did not show signs of residual shunting (grade 0) in 15 patients and demonstrated a grade I shunt in 6 patients and a grade II shunt in 8. A grade III immediate residual shunt was demonstrated in two patients, both of whom had undergone repair of tetralogy of Fallot (Fig. 1B). The interobserver variation for the grading of immediate residual shunting by contrast studies was 6%.

Table 2. Immediate Residual Shunting Detected by Intraoperative Studies in 31 Patients

Technique	Analysis	No. of Observations			
		Grade 0	Grade I	Grade II	Grade III
Color flow mapping	Real time.	2	20	8	1
	frame by frame*	11	13	6	1
Contrast	Real time.	15	5	8	2
echocardiography	reduced speed†	16	4	8	2

*Diastolic or early systolic turbulence alone was judged not to represent residual shunting (grade 0). †Reduced speed analysis of one study revealed interatrial shunting and thus the study was uninterpretable.

Slow motion analysis (Table 2). Subsequent repeat analysis of the epicardial two-dimensional echocardiographic imaging studies revealed no instances of patch dehiscence. Frame by frame analysis of color flow mapping studies revealed turbulence restricted to early diastole in five patients and turbulent peripatch flow abnormalities occurring only during early ventricular systole in four patients (Fig. 2). All of these patients had been judged to have a grade I shunt during the real time analysis. Twenty patients (65%) showed holosystolic peripatch turbulence that was judged to be grade I in 13 patients, grade II in 6 (Fig. 3) and grade III in 1. Systolic transseptal flow at the suture line of the prosthetic patch could be detected in only four of these patients. The difference between the results of the real time and frame by frame analysis of the color flow mapping studies was significant ($p < 0.025$). Color flow mapping allowed definition of the precise site of residual shunting in all patients. No patient was found to have an overlooked additional muscular defect.

Reduced speed analysis of contrast studies did not confirm a previously determined grade I residual shunt in one patient. In another patient, residual interatrial shunting was detected and the ventricular contrast study was judged to be uninterpretable. Thus, reduced speed analysis confirmed residual interventricular shunting in 14 patients, of whom 4 were judged to have a grade I shunt, 8 a grade II shunt and 2 a grade III shunt. Nine of these 14 patients with positive contrast studies had a scan including the right ventricular outflow tract (Fig. 4), whereas 5 did not. In comparison, a scan position that demonstrated both the right ventricular outflow tract and the main pulmonary artery was chosen in only 3 of the 16 patients who showed no contrast effect in the right ventricle. In the remaining 13 patients, the scan position was either a foreshortened four chamber view and/or a left ventricular long-axis view, or both, chosen in an attempt to detect and localize residual shunting at the same time. The yield of positive contrast studies was therefore related to whether or not the imaging plane included the right ventricular outflow tract ($p < 0.05$). Contrast echocardiography as performed in this series did not allow the precise localization of the site of residual shunting.

Follow-up studies. Six (20%) of the 30 patients who were followed up were found to have a persistent interventricular shunt. This was judged to be of no hemodynamic significance in five patients and of little significance in one patient whose postbypass contrast study demonstrated grade III shunting. Another patient was found to have a small residual shunt on an ultrasound investigation 1 month postoperatively but underwent spontaneous closure of the defect because the second follow-up study 14 months after the operation was normal. Neither early nor late reoperation for residual shunting nor invasive shunt size determination was required on clinical grounds in any patient.

Risk of long-term shunts (Table 3). Two patients were judged to be at high risk of having a persistent residual shunt because they showed a grade III shunt on studies immediately after bypass. Both had a residual defect at ultrasound follow-up studies performed, respectively, 13 and 9 months after operation. Ten patients were suspected to be at moderate risk. On follow-up studies 7 and 10 months after surgery, respectively, two of them were found to have a residual defect and a third patient underwent spontaneous closure of a defect. The remaining seven patients did not show residual shunting after a mean interval of 8 months. A low risk for having a persistent residual shunt was assumed in the 11 patients who showed a grade I shunt either on color flow mapping or contrast postbypass studies. Two of these 11 were found to have a persistent residual shunt at late follow-up study. One of these patients was observed to have a left ventricular to right atrial shunt at the follow-up study. Because this was excluded at the time of the postbypass color flow mapping study, late patch dehiscence must be suspected in this case. The second patient had undergone an arterial switch procedure for transposition of the great arteries at the age of 2 weeks; left to right pressure differences at the time of postbypass study were minimal. The late follow-up study in this case demonstrated a tiny jet at the inferior suture line of the patch. None of the eight patients who did not have any sign of immediate residual shunting detected by reduced speed analysis of the postbypass studies was found to have a persistent shunt on follow-up study.

Complications. Isolated ventricular premature beats or self-terminating episodes of ventricular tachycardia (maximum of five ventricular beats in succession) were encountered occasionally, but never required treatment. No epi-

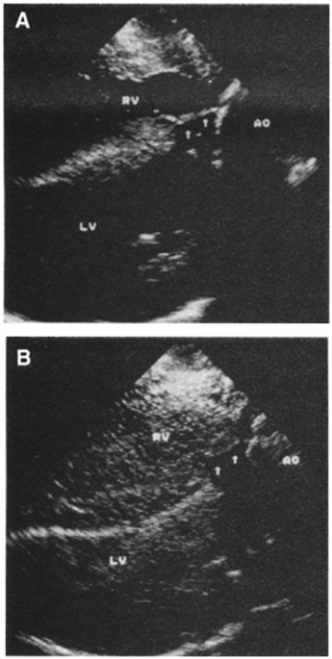

Figure 1. A, postbypass epicardial two-dimensional echocardiographic imaging in a long-axis view after correction of tetralogy of Fallot. The two-dimensional image clearly demonstrates the ventricular patch (**arrows**) to be in situ; there are no signs of patch dehiscence. B, The subsequent contrast echocardiographic study reveals a uniform and dense contrast effect in the right ventricle (RV), which exceeds 50% of the contrast effect in the left ventricle (LV), indicating grade III residual shunting. The large area of echo masking posterior to the prosthetic patch (**arrows**) is also well demonstrated. AO = ascending aorta.

sodes of bacterial endocarditis or infective pericarditis were reported.

Discussion

Ideally, intraoperative echocardiography in congenital heart disease should provide specific, quantitative and reproducible information about the surgical results achieved in each patient. Such data would enable the surgeon to decide if any residual lesion required reoperation during a second period of cardiopulmonary bypass. However, as demonstrated in the present study, achievement of this goal in practice meets with several difficulties. Because the hemodynamic situation immediately after cardiopulmonary bypass is considerably altered from normal and is rapidly changing, it may be unrealistic to expect that attempts to quantify residual shunting at a particular moment will indicate the true long-term result. Similar limitations apply to the use of oximetry or dye-dilution techniques. These were not performed because their value in the determination of shunt size in the immediate postbypass situation remains questionable (14).

Color flow mapping. Doppler ultrasound is a highly sensitive technique for detecting residual shunting (4–7); however, shunt size determination remains problematic. In the intraoperative setting, measurements of flow areas or more elaborate methods for pulsed Doppler-derived calculation of shunt volumes are too time-consuming and unreliable to be of practical value. Therefore, a semiquantitative approach seemed to be more appropriate for grading the severity of immediate residual shunting.

Real time assessment of color flow mapping studies for the grading of residual shunting was found to be problematic, as reflected by the considerable interobserver variability in this study. In several patients, turbulence confined to diastole or early systole was misinterpreted as residual systolic shunting. Isolated diastolic turbulence has not been reported before in this context, but seems to be related to turbulent ventricular inflow over the prosthetic patch. The cause of turbulence occurring only in early systole is not certain, but it is possible that it is a "normal" and transient phenomenon after ventricular septal defect closure. Irrespective of the causes of these phenomena, our experience suggests that exact timing of the occurrence of any depicted peripatch or paraseptal turbulence is required. However, frame by frame analysis of the color flow maps is too time-consuming during surgery for this to be practical. Therefore, we suggest that intraoperative color M-mode studies should be performed routinely for the exact timing of any residual flow turbulence.

Other limitations of postbypass epicardial color flow mapping for the detection of residual shunting arise in the presence of near equal residual peak systolic pressure in the ventricles caused by either a large residual defect, residual right ventricular outflow obstruction or reactive pulmonary hypertension. This will result in laminar shunting across any residual defect, which is then difficult to assess on-line. Residual right ventricular outflow tract obstruction produces turbulence in systole, which may mask any residual shunt after the closure of a perimembranous outlet defect. A further limitation of color flow mapping is that any prosthetic

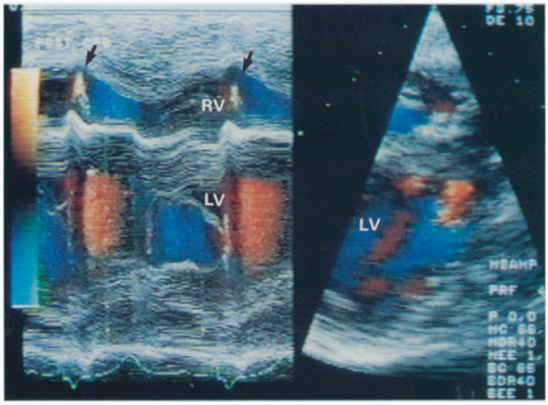

Figure 2. Epicardial color flow mapping study (long-axis view) (**right**) in a patient after patch closure of a perimembranous outlet defect. A small area of turbulent flow at the right lateral side of the patch suture line was initially misinterpreted as a residual grade I shunt. However, the color M-mode study (**left**) demonstrated only early systolic turbulent flow (**arrows**) not indicative of true residual shunting. Abbreviations as in Figure 1.

material used in the repair is likely to produce ultrasound masking behind it in the color flow maps. This greatly limits the detection of transseptal blood flow, which might otherwise be a cardinal feature of residual interventricular shunting. Finally, it is often difficult to image the apical part of the interventricular septum from the epicardium because the large size of current transducers compared with the size of the sternotomy restricts probe angulation and thus small apical muscular defects might be missed. Despite these major limitations, epicardial color flow mapping is the best technique to identify the exact site of a residual shunt.

Intraoperative transesophageal echocardiography is, in our experience, a poor substitute for the epicardial technique (15). Any prosthetic material used in the repair will result in large areas of ultrasound masking of the right ventricle, both

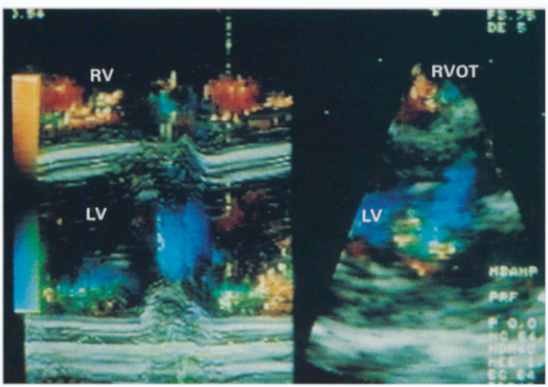

Figure 3. Color flow mapping study (long-axis view) (**right**) in a patient after patch closure of a perimembranous outlet ventricular septal defect, revealing a broad and short jet (grade II) reaching into the right ventricular outflow tract (RVOT). The simultaneously performed color M-mode study (**left**) documents the holosystolic flow pattern of the residual shunt. Abbreviations as in Figure 1.

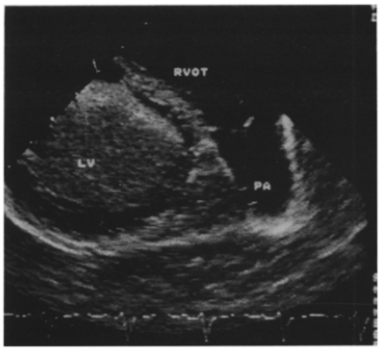

Figure 4. Contrast echocardiographic study in the right ventricular outflow long-axis view. The left ventricle (LV) is cut in short axis and the right ventricular outflow tract (RVOT) and the main pulmonary artery (PA) in long axis. With use of this view, the definite exclusion of residual left to right shunting, as in this patient, can be made with a single injection of contrast medium into the left atrial line.

on the two-dimensional image and on the color flow maps, precluding the reliable exclusion of residual shunting.

Contrast echocardiography. In the present study, contrast echocardiography allowed a more reproducible semiquantification of residual shunting than did color flow mapping, but it was unable to define the exact site of shunting. The use of modified four chamber views during contrast studies is problematic as these may miss residual shunting detected by color flow mapping because the contrast medium appearing in the right ventricular outflow tract may be washed out before it fills the whole cavity. Our experience suggests that the definite exclusion of residual shunting or its detection and semiquantification is best performed with a single contrast injection made while scanning a right ventricular outflow long-axis view (Fig. 4). This unique epicardial view is obtained by placing the transducer on the right ventricular epicardium near the acute margin and midway between the right ventricular apex and the atrioventricular groove and by scanning upward from there toward the outflow tract.

Table 3. Estimation of Risk of Long-term Residual Shunting by Combined Intraoperative Studies in 30 Patients

Estimated Risk	Immediate Shunting on Either CFM or CE	No.	Long-term Shunt
High	Grade III shunting	2	2
Moderate	Grade II shunting	10	2 (3)*
Low	Grade I shunting	11	2
None	No residual shunting	8	0

*One patient was documented to have undergone spontaneous closure of a defect. CE = contrast echocardiography; CFM = color flow mapping.

Intraoperative study scheme. From this experience of intraoperative echocardiography in patients who have undergone surgical closure of a ventricular septal defect, we suggest that postbypass studies for residual shunting should be performed according to the following scheme, which initially uses contrast echocardiography to rapidly exclude or establish residual shunting, and then color flow mapping to determine its exact site:

1) Routine postbypass two-dimensional echocardiographic epicardial imaging and color flow mapping in standard planes to assess the surgical repair in general and exclude residual lesions such as valvular regurgitation or outflow tract obstruction.

2) Contrast echocardiographic studies with the injection of contrast medium into the left atrial line while scanning a right ventricular outflow long-axis view that includes the proximal pulmonary artery.

3) If residual shunting is demonstrated by contrast echocardiography, color flow mapping should be performed in long-axis, four chamber and short-axis views of the interventricular septum to determine the site of any residual turbulent flow across the interventricular septum or adjacent to the patch.

4) Color M-mode recordings of the turbulence should be made to document its precise timing and duration in the cardiac cycle.

Significant shunting. The main goal of postbypass intraoperative ultrasound studies after closure of ventricular septal defects is the exclusion or detection of a significant residual shunt. Our late postoperative echocardiograhic findings indicate that immediate reoperation should be considered in those patients who are found to have gross patch dehiscence on epicardial imaging (not encountered in this series) or who are judged to be at high risk of having a residual shunt. Such patients demonstrate dense echocardiograhic contrast in the right ventricle or pulmonary artery during contrast studies (visually estimated at >50% of the density of contrast in the left ventricle) and pansystolic turbulence at the site of the repair on color flow mapping, with a broad jet that expands into the right ventricle. However, the surgical decision to undertake further repair must inevitably be guided in each individual case by both its feasibility and risks.

Long-term shunting. Except in patients with a grade III immediate residual shunt, the predictive value of minor degrees of immediate residual shunting for estimation of the risk of long-term residual shunting was limited. There are several possible explanations for this finding. For example, small residual defects may close spontaneously, thereby

reducing the specificity of immediate postbypass studies compared with long-term follow-up studies, or late patch dehiscence may occur, which would reduce their sensitivity. In our study, we identified one patient with late spontaneous closure of a small residual defect and another with a left ventricular to right atrial shunt that had not been present immediately after bypass. Further studies with frequent serial investigations after surgery are needed to correlate the results of postbypass echocardiographic examinations with the risks of a residual ventricular septal defect and to allow better understanding of the natural history of small residual shunts.

Conclusions. A combination of intraoperative contrast echocardiography and color flow mapping can allow the detection or definite exclusion of a significant residual defect immediately after closure of ventricular septal defects. These techniques provide the surgeon with very valuable information in patients with a significant residual shunt when immediate revision of the repair can be considered. However, at present, their ability to predict long-term results is limited.

References

1. Allen HD, Anderson RC, Noren GK, Moller JH. Postoperative follow-up of patients with ventricular septal defect. Circulation 1974;50:465–70.
2. Vincent RN, Lang P, Chipman CW, Castaneda AR. Assessment of hemodynamic status in the intensive care unit immediately after closure of ventricular septal defect. Am J Cardiol 1985;55:526–9.
3. Lang P, Chipman CW, Siden H, Williams RG, Norwood WI, Castaneda AR. Early assessment of hemodynamic status after repair of tetralogy of fallot: comparison of 24 hour (intensive care unit and 1 year postoperative data in 98 patients). Am J Cardiol 1982;50:795–9.
4. Stevenson JG, Kawabori I, Stamm SJ, et al. Pulsed Doppler echocardiographic evaluation of ventricular septal defect patches. Circulation 1984; 70:138–46.
5. Ludomirsky A, Huhta JC, Vick GW, Murphy DJ, Danford DA, Morrow WR. Color Doppler detection of multiple ventricular septal defects. Circulation 1986;74:1317–22.
6. Ortiz E, Robinson PJ, Deanfield JE, Franklin R, Macartney FJ, Wyse RKH. Localisation of ventricular septal defects by simultaneous display of superimposed colour Doppler and cross sectional echocardiographic images. Br Heart J 1985;54:53–60.
7. Sutherland GR, Smyllie JH, Ogilvie BC, Keeton BR. Colour flow mapping in the diagnosis of multiple ventricular septal defects. Br Heart J 1989;62:243–9.
8. Kirklin JK, Castaneda AR, Keane JF, Fellows KE, Norwood WI. Surgical management of multiple ventricular septal defects. J Thorac Cardiovasc Surg 1980;80:492–9.
9. Valdez-Cruz LM, Pieroni DR, Roland JM, Shematek JP. Recognition of residual postoperative shunts by contrast echocardiographic techniques. Circulation 1977;55:148–52.
10. Gussenhoven EJ, van Herwerden LA, van Suylen RJ, et al. Recognition of residual ventricular septal defect by intraoperative contrast echocardiography. Eur Heart J 1989;10:801–15.
11. Spotnitz HM, Malm JR. Two-dimensional ultrasound and cardiac operations. J Thorac Cardiovasc Surg 1982;83:43–51.
12. Andrade JL, Serino W, de Leval M, Somerville J. Two-dimensional echocardiographic assessment of surgically closed ventricular septal defects. Am J Cardiol 1983;52:1–9.
13. Gussenhoven EJ, van Herwerden L, Roelandt J, Ligtvoet KM, Bos E, Witsenburg M. Intraoperative two-dimensional echocardiography in congenital heart disease. J Am Coll Cardiol 1987;9:565–72.
14. Engerleider RM, Greeley WJ, Sheikh KH, Kern FH, Kisslo JA, Sabiston DC. The use of intraoperative echo with Doppler color flow imaging to predict outcome after repair of congenital cardiac defects. Ann Surg 1989;210:526–33.
15. Stümper O, Kaulitz R, Sreeram N, et al. Intraoperative transesophageal versus epicardial ultrasound in surgery for congenital heart disease. J Am Soc Echo, in press.